NORWEGIAN HYDROPOWER CENTRE

A PRESENTATION OF MASTER STUDENTS AND PHD CANDIDATES

SPRING 2015

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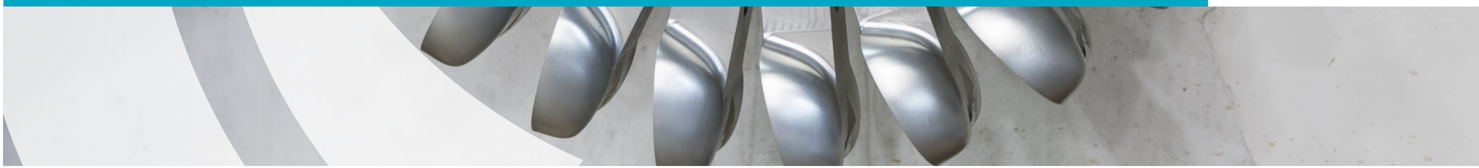

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Future competence

It is a pleasure to present this compilation and outline of the academic and educational projects and research executed within the Norwegian Hydropower Centre as of spring 2015. The centre is a collaborative platform at NTNU and within its sector, bridging education, science and industry.

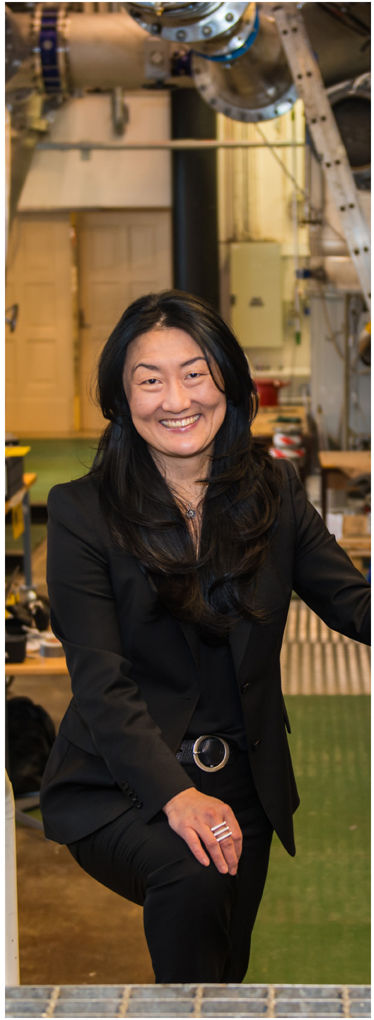
The catalogue shows an impressive diversity in its approach towards important research-issues regarding hydropower technology. It is a very promising exhibit for delivering on the upcoming competence-needs in the hydropower sector and the future science communities.

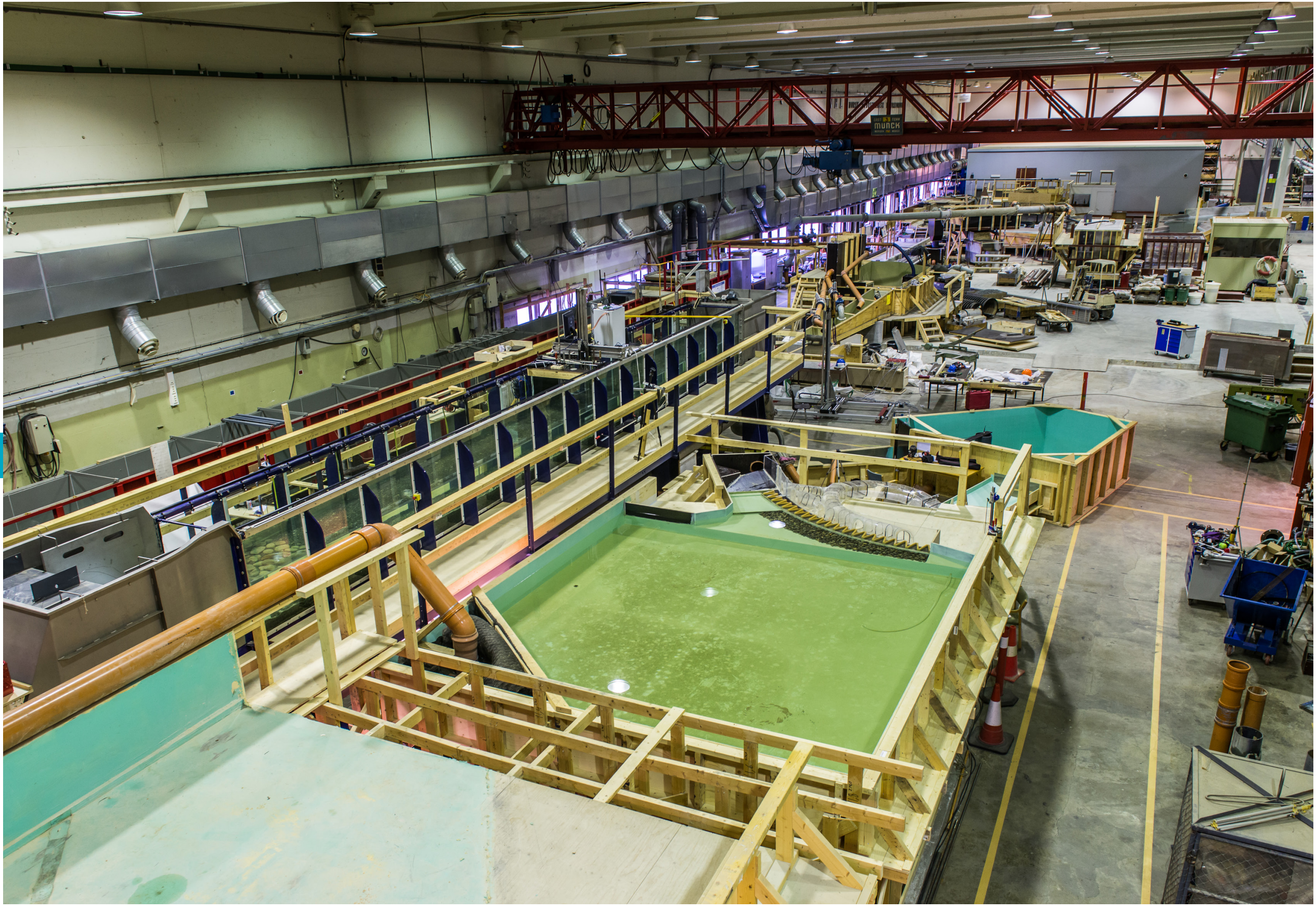
The Norwegian Hydropower Centre is a national centre focused on research and education in hydropower technology. The centre is a cooperation between universities, research institutions, industry and authorities.

The Norwegian Hydropower Centre's mission is to be a driving force to sustain and develop effort and resources on education, research and development within the Norwegian hydropower sector. The outcomes presented here defines the valuable competence and knowledge that are accessible for the sector, both for recruitment and for future research.

Enjoy!

Kind regards
Hege Brende
Executive Manager



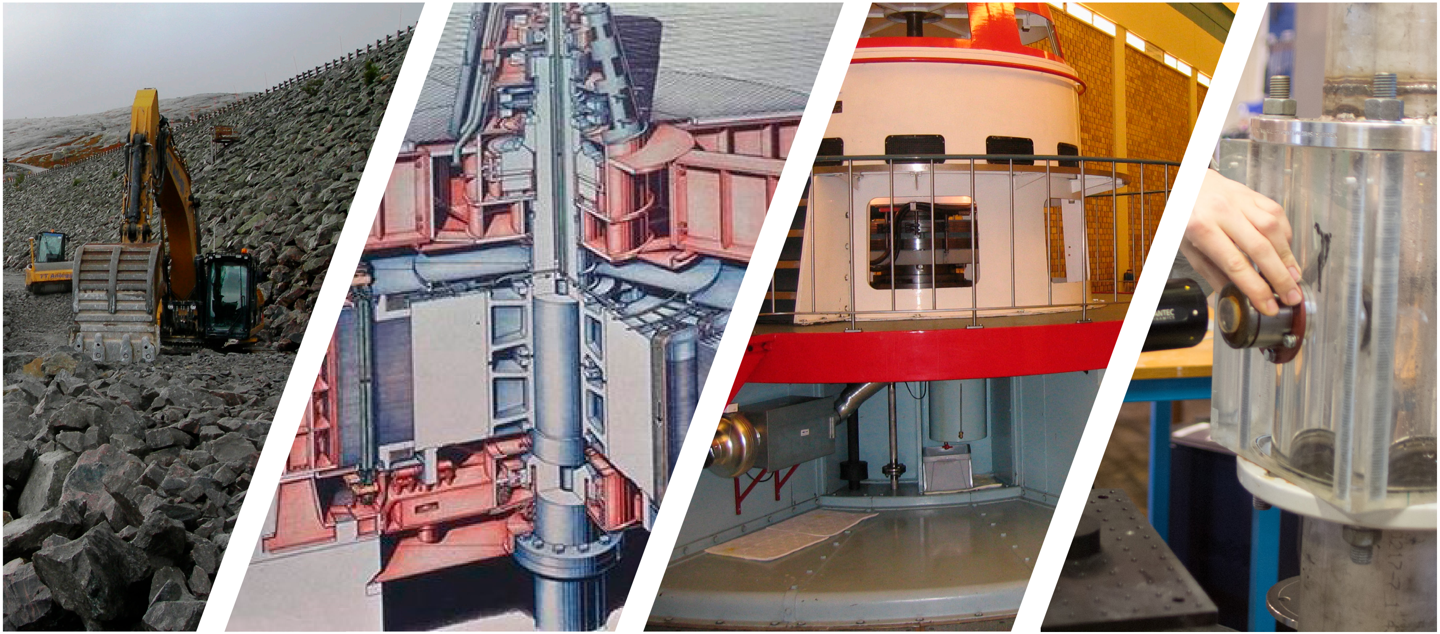

MUNCK

Introduction

We present here both master students and PhD candidates writing their theses under the Norwegian Hydropower Centre.

As a collaborative platform we gather the four main departments at NTNU that work specifically with hydropower technology: mechanical engineering, hydraulic engineering, engineering geology and electrical engineering.

All of the following students and candidates are affiliated to one of these four disciplines and departments.



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NORWEGIAN HYDROPOWER CENTRE

DEPARTMENT OF ENERGY AND PROCESS ENGINEERING – WATERPOWER LABORATORY

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Waterpower Laboratory

Efficiency and Pressure Pulsation Measurements at Low Head Hydropower Plants

By Anders Jensen Aas

Supervisor: Ole G. Dahlhaug

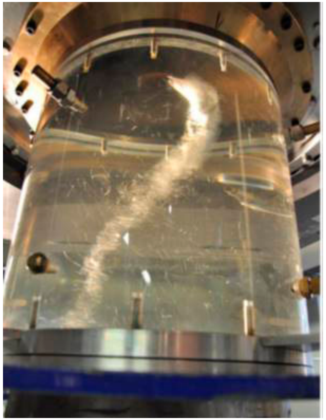
NTNU – Trondheim
Norwegian University of Science and Technology

Background

The purpose of the this thesis will be to perform both efficiency measurements and measurements of pressure pulsations in three low head power plants in Nidelva. These three are; Øvre Leirfossen, Nedre Leirfossen and Leirfossene Power Plant.

The efficiency measurements at Øvre and Nedre Leirfoss will be done with Pitot, while the efficiency measurements at Leirfossene will be done with both Gibson's method and with thermodynamic method. These methods will then be compared with each other and similar measurements at other power plants.

The pressure pulsations will be measured in the draft tubes of all three power plants.



This picture shows a cavitated whip at part load in the draft tube of a francis runner. Which will cause pressure pulsations.

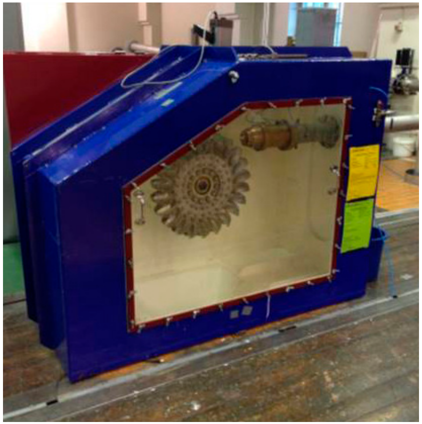
This picture show two Pitot tubes used measure the volume flow at Øvre Leirfoss Power Plant.

Background

Even though the Pelton turbine is more than a 100 year old invention, there are still some areas with a lack of knowledge. Amongst them is the flow in the turbine buckets, coming from the water jet. A model of a runner has been made in the Waterpower Laboratory to get a deeper understanding of this topic.

Objective

In this master thesis tests of the runner will be carried out, and the different flow patterns for different running condtions will be analyzed. Both standard tests and tests with the use of a high-speed camera, using an onboard borescope mounted to the runner itself, will be conducted. If time allows it, particles may be placed in the flow and the trajectories filmed.



Pelton turbine model.
Photo: Master thesis by Martine Wessel.

Flow in a bucket. This picture is taken with 25 m head, nozzle opening of 10 mm and n11 = 38,5.
Photo: Master thesis by Martine Wessel.

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Master Thesis
Waterpower Laboratory

Pelton Turbine – Model Test of a Runner

By Audun Tufte Larsen

Supervisor: Ole Gunnar Dahlhaug

NTNU – Trondheim
Norwegian University of Science and Technology

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NORWEGIAN HYDROPOWER CENTRE

Master Thesis
Waterpower Laboratory

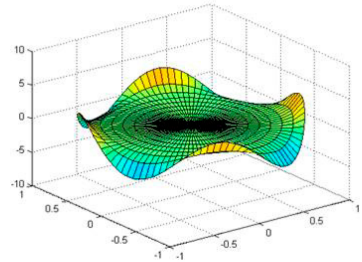
Measurement of Natural Frequencies in a Circular Disk in Air and Water

By Frode Kristoffer Amundsen Kjøsnes

Supervisor: Pål-Tore Storli
Co-supervisor: Torbjørn K. Nielsen, Petter Østby

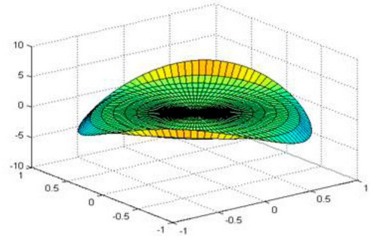
NTNU – Trondheim
Norwegian University of
Science and Technology

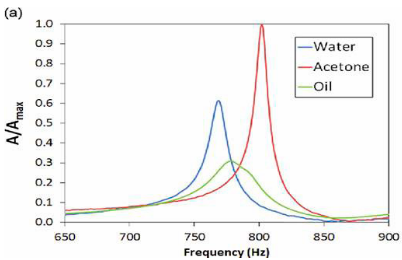
Some new high head Francis runners have experienced that resonance is excited during operation and caused fatigue fractures. Therefore the natural frequency is a important characteristic of high head Francis runners. However, the natural frequency of the runner is dependent of the medium it is surrounded by and nearby rigid surfaces. This is called the added mass effect, and it makes it difficult to predict the natural frequency of the runner while it is in operation.

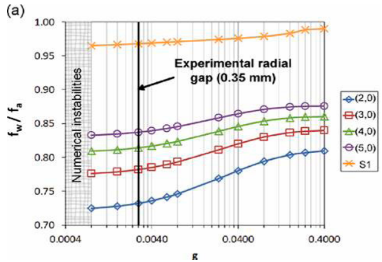


Goals

- Identify the current research status on natural frequencies of Francis runners, and other rotating constructions.
- Do response frequency measurements on a disc and pump turbine.
- Identify the added mass effect of water through experiments.







Valentín, D., et al., Experimental study on the added mass and damping of a disc submerged in a partially fluid-filled tank with small radial confinement. Journal of FluidsandStructures(2014), http://dx.doi.org/10.1016/j.jfluidstructs.2014.06.006i

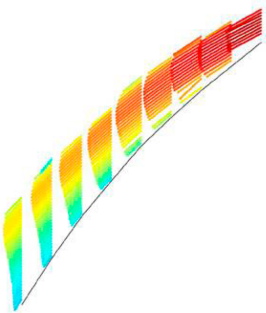
Background

Multistage centrifugal pumps with diffuser vanes are used in the oil industry to pump produced water, i.e. water which is separated from the oil. The produced water contains salt water with small oil droplets. Because of environmental regulations, the oil droplets need to be separated from the produced water before the water is released back into the sea. The efficiency of the separation process is dependent on the size of the oil droplets. It is therefore desired to obtain the optimal size. The pumps that are used today has a tendency of making the droplets smaller. A company in Stavanger, Norway named Typhonix is researching on a multistage centrifugal pump which under certain operating conditions is able to enlarge the oil droplets. The increase in droplet size increases the energy efficiency of the separation process compared to the traditional pumps.

This thesis is a continuation of the work done in my project thesis. A test rig for the centrifugal pump has been built in the Waterpower laboratory. The flow characteristics in the diffuser of the pump will be investigated further and more thoroughly, providing PhD. candidate Alessandro Nocente with experimental data. The equipment used for measuring the velocity is Laser Doppler Velocimetry (LDV). This data will be compared with a CFD simulation performed in Fluent to possibly verify the numerical model.

In addition a mesh sensitivity analysis of the numerical model will be performed. The mesh will be modified by using Ansys ICEM. Also, the solution from Fluent will be compared with a OpenFOAM solution.

The diffuser of the test rig



Velocity field of the diffuser, results from the project thesis

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Master Thesis
Waterpower Laboratory

LDV Measurements in Centrifugal Pump Diffuser

By Karl Oskar Pires Bjørgen

Supervisor: Torbjørn K. Nielsen
Co-supervisor: Alessandro Nocente

NTNU – Trondheim
Norwegian University of Science and Technology

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Waterpower Laboratory

Study of Sediment Erosion in Guide Vanes of Francis Turbine

By Linda Haugvaldstad

Supervisor: Ole Gunnar Dahlhaug

NTNU – Trondheim
Norwegian University of
Science and Technology

Background

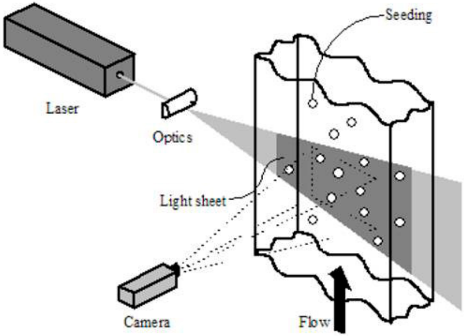
Sediment erosion in Francis turbines is a large problem for river power plants near the Himalayas and the Andes Mountains. The turbines at Jhimruk Power Plant in Nepal need to be maintained annually due to high erosion wear, resulting in reduced energy production and high costs. It is therefore of interest to have deeper knowledge of relation between flow behavior and sediment erosion in Francis turbines.

The aim is to carry out experimental tests to identify effects of sediment erosion on guide vanes of Francis turbines.

PIV, pressure sensors and logging system are going to be installed for velocity and pressure measurements.

A visit to the Turbine Testing Laboratory at Kathmandu University in Nepal, to make arrangements for a similar test rig, is also a part of the thesis.

Erosion damage of guide vane



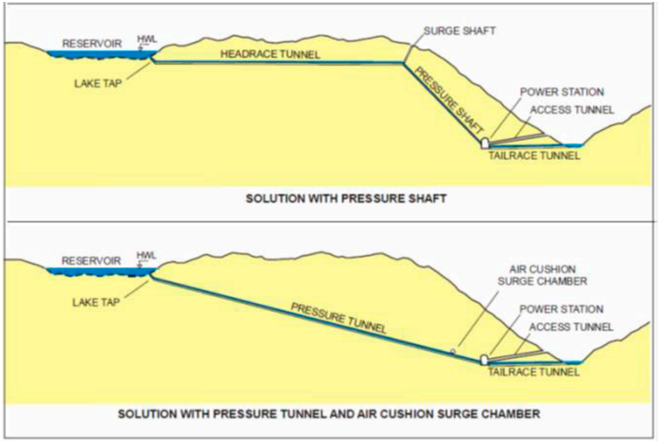
Components needed for PIV measurements

Background

Herand power plant falls in under the requirements set by FIKS, which states that all power plants with a generator of 10MVA or more must have frequency regulation and be able to operate in an isolated grid.

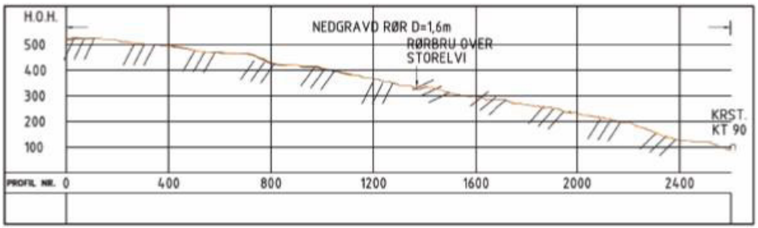
The conduit dynamics of Herand Power plant will be examined by the use of transfer functions that result in AFF diagrams. These AFF diagrams are used to conduct a stability analysis of Herand power plant.

Due to challenging topography, an air cushion surge chamber will be implemented, and the optimal dimensions and location of said air cushion surge chamber will be obtained.



Surge shaft vs air cushion surge chamber

In addition, the flow is limited and the only flow regulation will be the natural regulation of Fodnastølsvatnet. Therefore, different points of operation will be studied, especially at low flow availability.



Altitude profile at Herand

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Master Thesis
Waterpower Laboratory

Conduit dynamics in Herand Power plant

By Siri S. Sletten

Supervisor: Pål-Tore Selbo Storli

NTNU – Trondheim
Norwegian University of Science and Technology

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Waterpower Laboratory

Surge Shafts or air Cushions in Hydropower Plants

By Torunn Engen Røse

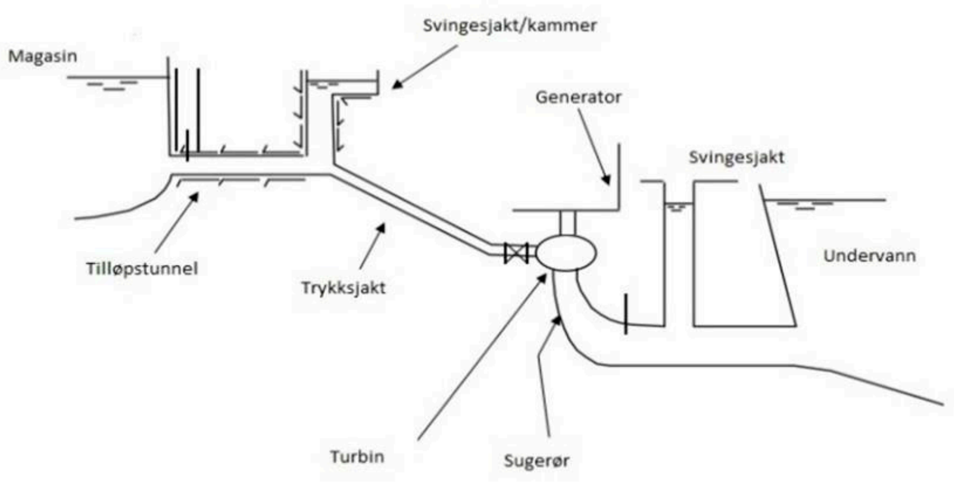
Supervisor: Torbjørn K. Nielsen

NTNU – Trondheim
Norwegian University of
Science and Technology

Background

Skagerak Kraft are going to build a hydropower plant, Sauland, in Hjartdal in Telemark. The power plant have two waterfalls they will utilize and one common tailrace tunnel.

In the project the stability and dynamics in the power plant were evaluated for the first waterfall. In the thesis the simulations and analytical calculations will look at the whole power plant with the two headrace tunnels.
Both of the headrace tunnels need surge chambers. An alternative is to build air cushions, instead of the normal surge shaft. Both surge alternatives will be analyzed, to find the best alternative. It should also take into account the effect of implementing different dampening models. In the end the stability of a hopefully optimal solution will be evaluated.



Background

In recent years several high head Francis turbines have experienced breakdown after a short time of operation. It is thought that these breakdowns is caused by Runner Stator Interaction (RSI) which induces pressure pulsations on the runner. If these pulsations have a frequency close to the natural frequency of the runner, resonance can occur and, in a short amount of time, cracks or total failure could be the result. To avoid this, an understanding of the natural frequencies of the turbine is important for turbine manufactures. The natural frequencies of the runner depends on a number of factors, which need to be modelled, in order to get accurate calculations, even at an early stage of runner construction.

The recent beakdowns is the best proof of the lack of knowledge concerning this problem. The goal of this thesis is to check the computer simulated frequencies against the measured frequencies from a model

Damaged runner, Svartisen, Norway

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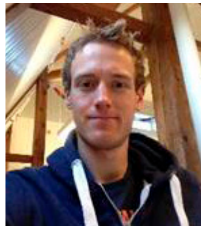
Master Thesis

Waterpower Laboratory

Simulation of Natural Frequencies of a Francis Turbine in Air and Water

By Øyvind Moen Fjeld



Supervisor: Torbjørn Nielsen

NTNU – Trondheim
Norwegian University of
Science and Technology

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PhD Thesis
Waterpower Laboratory

Flow in Pelton Turbines

By Bjørn Winther Solemslie

Supervisor: Ole Gunnar Dahlhaug
Co-Supervisor: Torbjørn K. Nielsen

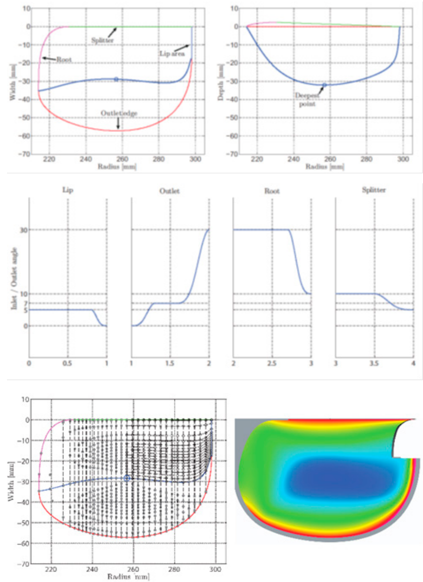
NTNU – Trondheim
Norwegian University of
Science and Technology

Background

The Pelton turbine is an old technology, but there are still gaps in the knowledge concerning the flow within the turbine and the flow mechanisms that govern it.

To enable a greater possibility of collaboration within the researchers working on the Pelton turbine an open reference turbine has been designed and is used as the test case for the study of the flow.

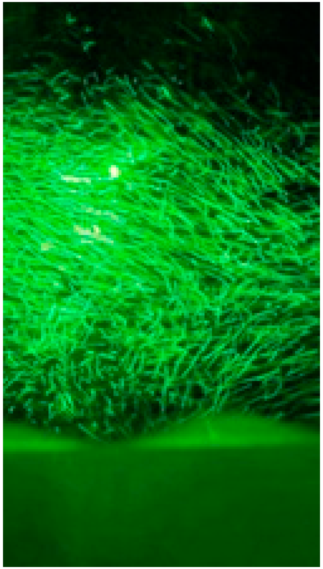
The turbine will be fitted with an on board boroscope to enable inspection of the bucket within the rotating frame. The boroscope will be connected to a SA5 High Speed Camera that will make it possible to investigate the flow within the Pelton turbine relative to the turbine. This will again give the possibility to look closely at the flow mechanisms affecting the flow and possibly acquire the stream lines and relative velocities within the flow field.

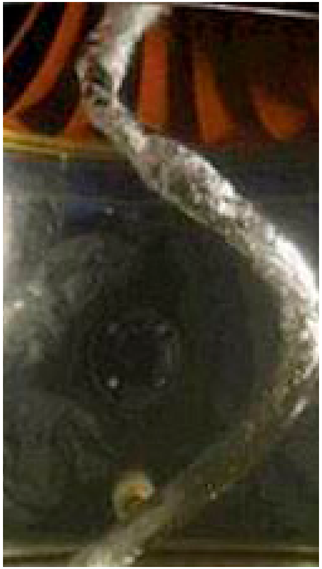


Background

Varying demand for power requires turbines to be operated at part load more frequently, and turbines are subject to more frequent load variations than have been seen before. These conditions induce phenomena that can be difficult to simulate using CFD, due to lacking experimental data available.

The aim of this thesis is to experimentally investigate the phenomena occuring at off-design operation of a high head Francis turbine and during transient operation. The data produced will be submitted to the Francis-99 workshops, a series of workshops aiming at establishing the state-of-the-art for CFD simulation of Francis turbines. The results will also be used to determine the correlation between the transient flows occuring in the runner, and the crack porpagation in the runner caused by FSI.





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PhD Thesis

Waterpower Laboratory

High Head Francis Turbines

By Carl Bergan

Supervisor: Ole Gunnar Dahlhaug

NTNU – Trondheim
Norwegian University of
Science and Technology

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PhD Thesis
Waterpower Laboratory

Dynamics and Stability in Reversible Pump Turbines

By Magni Fjørtoft Svarstad

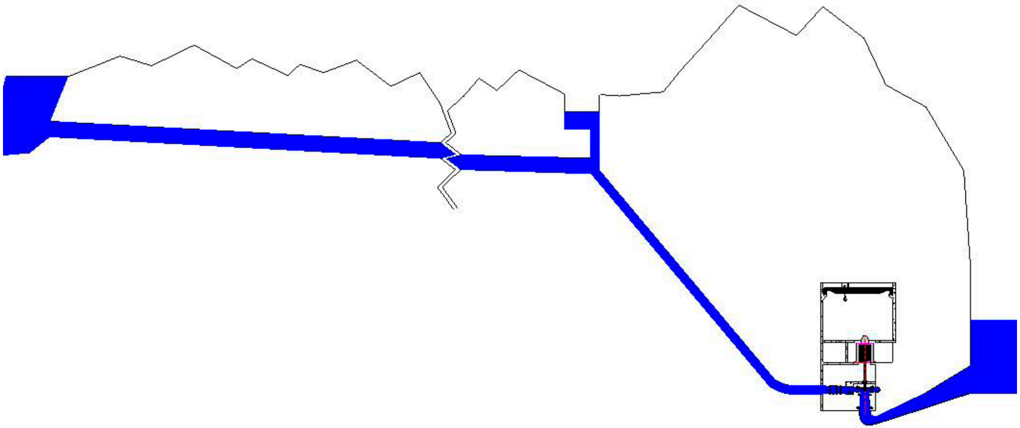
Supervisor: Torbjørn K. Nielsen

NTNU – Trondheim
Norwegian University of
Science and Technology

Background
Using reversible pump turbines to regulate the power in the power market requires a quick change in the operating situation of the machine. This doctoral thesis aims to increase the effectiveness of the change from pump to turbine mode of operation.

- Allowing water to be the driving force in changing the operational situation without total shutdown of the machine.

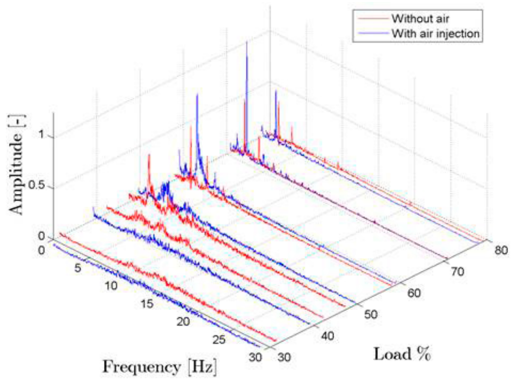
The hypothesis is that this method can be done without bigger strain on the machine than a normal start stop sequence and with lower probability of experiencing instabilities.



Background

Increased demand for flexibility in the power supply has lead to an increase in operation outside best efficiency point. Part load operation causes dramatic changes in the flow regime of the draft tube. For Francis turbines operating at part load, there is a mismatch between swirl generated by the guide vanes and the momentum extracted by the turbine runner. The vortex breakdown than occurring in the draft tube is recognized as the main cause of severe flow instabilities and pressure fluctuations. The consequences are known to be heavy vibrations and noise, which may cause high fatigue load and ultimately lead to mechanical failure. Mitigation of pressure pulsations is considered an imported task since it will increase the life time of the turbine.

Different methods for mitigating the vortex rope and the pressure fluctuations such as air injection, water injection, runner shaft extension have been investigated. The aim of this thesis is to further investigate these methods to find the best way of mitigating pressure pulsations.



Frequency analysis of a pressure pulsations in a Francis draft tube

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PhD Thesis
Waterpower Laboratory

Pressure Pulsations in Francis Turbines

By Peter Joachim Gogstad

Supervisor: Ole Gunnar Dahlhaug and Torbjørn K. Nielsen

NTNU – Trondheim
Norwegian University of Science and Technology

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PhD Thesis
Waterpower Laboratory

Dynamic Loads in Hydro Power Plants

By Rakel Ellingsen

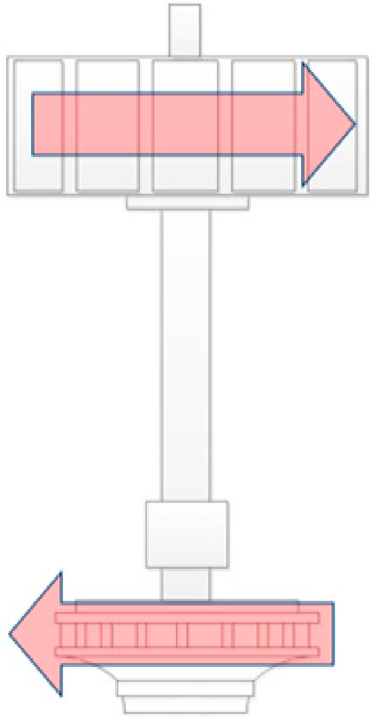
Supervisor: Pål-Tore Storli

NTNU – Trondheim
Norwegian University of
Science and Technology

Background

The variations in the grid frequency in the Nordic countries have increased during the last years. The turbines are also more often operated at part load or maximum load. In this project these effects will be studied, to see if they can explain why some relative new Francis turbines have experienced problems with cracks.

The generator's torque and the runner's torque are acting in opposite direction, and this leads to stresses in the material of the runner.



These stresses will be studied with Fluid Structure Interaction (FSI) where the effects from both the fluid side and the structural side of the turbine are simulated.

Different things need to be considered:

- The speed droop of the turbine
- The variations in grid frequency
- Design of the conduit system
- The governor
- Design of the runner
- The operation plan for the unit

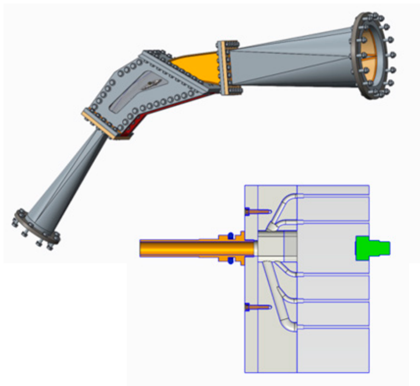
Background

Sediment erosion of turbine components has been a challenge for the hydro power plants under Himalayan and Andes basins. In Francis turbines, sediment erosion also causes increase of clearance between guide vanes and facing plates and cross flow occurs from the increased gap. This cross flow together with other secondary flows disturbs the velocity profile at the runner inlet. Change in velocity profile at the inlet causes additional erosion damage and other undesired effects in turbine runner. Examination of effects of increased cross flow from guide vanes on the flow conditions at the runner inlet will be main aim of this study.

Objectives

1. Study of causes and effects of erosion in Francis turbine operating in sediment flow.
2. Develop a test setup to create the flow conditions between guide vanes and runner inlet of a high head Francis turbine.
3. Investigate the effects of leakage flow around the guide vanes of high head Francis turbines on velocity distribution at the runner inlet.

Sediment erosion in Francis turbine components



Design of test setup

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PhD Thesis
Waterpower Laboratory

Sediment Erosion in Hydraulic Turbines

By Biraj Singh Thapa

Supervisor: Ole Gunnar Dahlhaug

NTNU – Trondheim
Norwegian University of Science and Technology

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PhD Thesis
Waterpower Laboratory

Separation Friendly Centrifugal Pumps

By Alessandro Nocente

Supervisor: Torbjørn Nielsen
Co-supervisor: Trygve Husveg

NTNU – Trondheim
Norwegian University of Science and Technology

Background

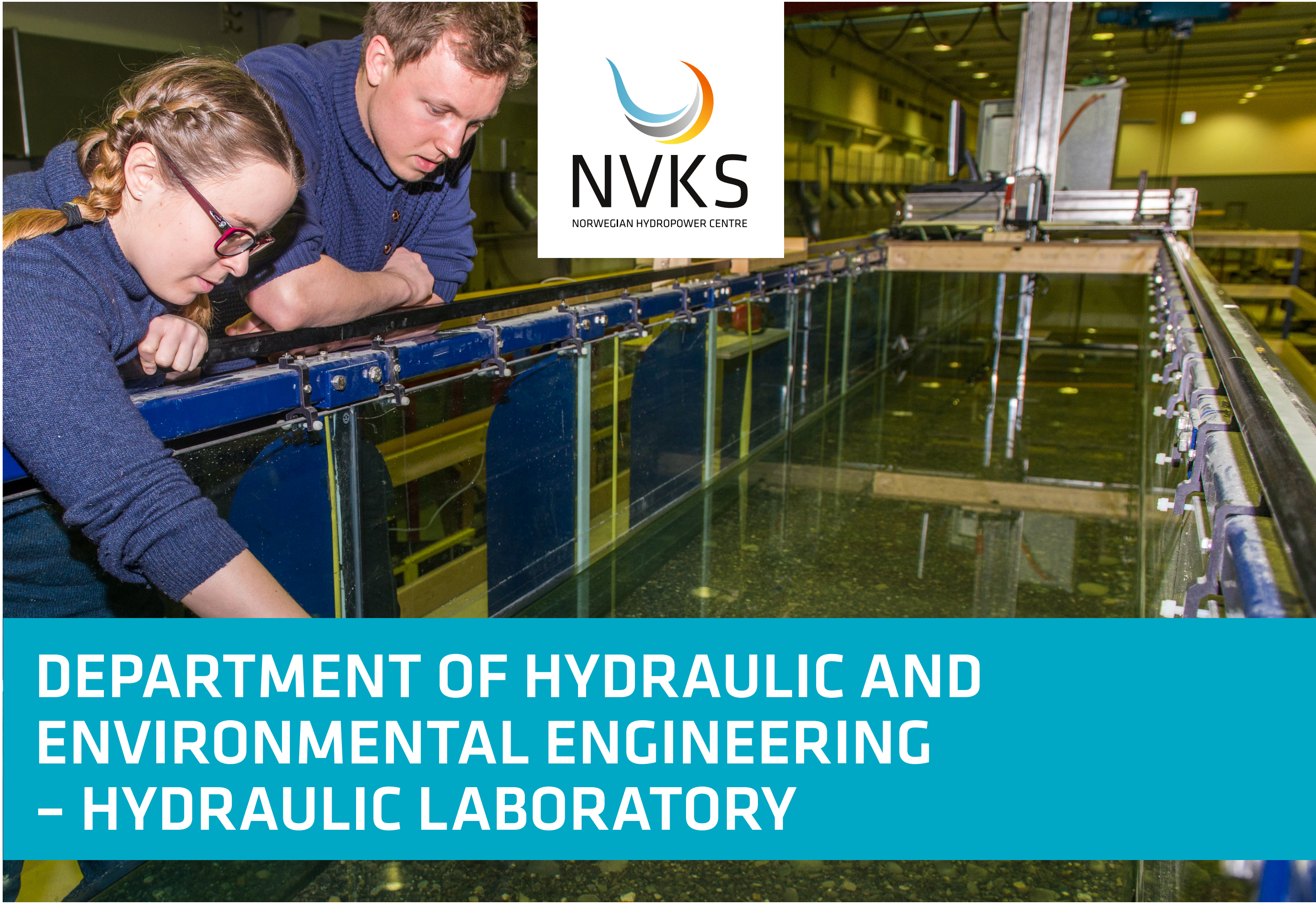
Produced water is by far the largest by-product of oil and gas industry and the removal of its oil content through hydrocyclones or other devices is a crucial environmental issue. In order to keep a high efficiency for these devices, the circulation of produced water must assure the lowest shear possible not to reduce the dimension of the dispersed phase.Typhonix AS conducted studies on centrifugal pumps for produced water which can replace the normally used screw pumps. These machines proved to apply low shear on the fluid. Furthermore they demonstrated to promote the coalescence of oil droplets.

Objective:

To study the flow circulation in the pump diffuser in order to characterize velocity, pressure and recurrent flow patterns and identify which design characteristics influence the growth of oil droplets.

Method:

CFD simulations of the flow through the diffuser, both single-phase and two-pase. LDV measurements on the centrifugal pump rig to characterize the flow and compare it with numerical results.
Further work: use the results to improve the diffuser design in order to get higher coalescence promotion.



DEPARTMENT OF HYDRAULIC AND ENVIRONMENTAL ENGINEERING – HYDRAULIC LABORATORY

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Master Thesis

Department of Hydraulic and Environmental Engineering

Modelling of Water Allocation and Availability in Devoll River Basin, Albania

By Christian Almestad

Supervisor: Knut Alfredsen
Tor Haakon Bakken

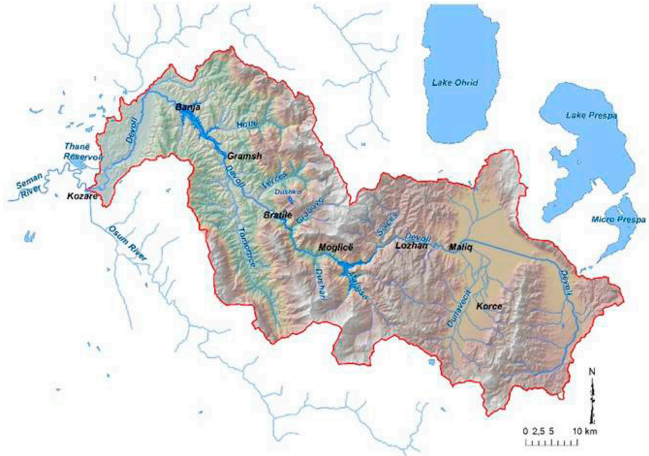
NTNU – Trondheim
Norwegian University of
Science and Technology

WEAP

Background

A growing population with an increasing economic development and consumption leads to massive use of the Earth's resources (Rockström et al., 2009). Many countries and regions experience water stress and ecological degradation of aquatic ecosystems, which is expected to further increase and accelerate with climate change (Bates et al., 2008; IPCC, 2011; IPCC, 2014). Due to global warming caused by anthropogenic greenhouse gas emissions, an increased the share of renewable energy production is needed, and large-scale investments in solar, wind and hydropower are expected (IPCC, 2011). Reservoirs are also key-stones in the infrastructure and prerequisite in water-stressed areas to secure adequate water-services to a large range of sectors, and are used for the purpose of securing irrigation, drinking water supply, flood control, navigation and more, as well as hydropower production.

The thesis will analyze how the design and operation of the reservoirs will affect water consumption and the availability of water for various purposes, including irrigation, drinking water supply and hydropower production. The study will be carried out using Devoll River Basin in Albania as a case, with an extensive on-going development with Norwegian ownership involved (Statkraft). A hydrological model of Devoll River Basin will be constructed using the Water Evaluation and Planning (WEAP) software tool. Future possible scenarios will be simulated and analyzed in WEAP to assess the impacts of climate change, and change in water consumption and demands due to population growth, improvements in technology and different policies for water allocation.



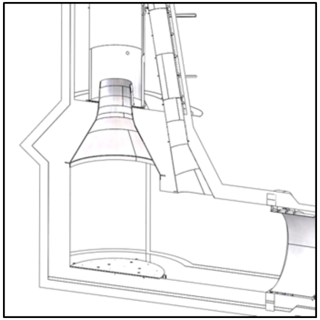
Background

Tonstad power plant is the largest power plant in Norway regarding to annual energy production. The water conduit was originally designed for 640 MW, and the latest addition of 320 MW has resulted in problems related to hydraulic transients. One of the major problems are related to the amplitude of mass oscillations in the three surge tanks. It is especially a concern that the water level in the surge tanks may be drawn down into the tunnel and release air in the waterway. By installing throttles in the surge tanks, it is possible to reduce the amplitudes.

Surge Tank Throttle

A surge tank throttle is a construction that reduces the flow area in the shaft of a surge tank to induce a great singular loss. The loss will contribute to better regulation stability by faster dampening the mass oscillations in the surge tank. Different configurations can be used to achieve different losses in upwards and downwards direction. An asymmetric throttle, from Reisseck II in Austria, is shown below.

Machine Hall, Tonstad Hydropower Plant



Asymetric throttle, Reisseck II

Thesis Objective

The objective of the thesis is to utilize a numerical model of Tonstad to find the optimal throttle losses for the surge tanks. A suggestion of throttle configuration is to be made, along with an economic analysis of the selected solution.

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NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Hydraulic and Environmental Engineering

Design of a Surge Tank Throttle for Tonstad Hydropower Plant

By Daniel Gomsrud

Supervisors:Leif Lia
Kaspar Vereide

NTNU – Trondheim
Norwegian University of Science and Technology

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Hydraulic and Environmental Engineering

Rip Rap of Embankment Dams – Effect of Interlocking Pattern on the Strength of The Rip Rap

By Eirik Helgetun Pettersen

Supervisors: Leif Lia and Priska H. Hiller

NTNU – Trondheim
Norwegian University of Science and Technology

Background

Norwegian embankment dams built after 1950 differs to some extent compared to international embankment dams by using clear separated zones where to grain size extends to bigger stones in the outer layers, called the rip rap. The stones in the rip rap is placed one by one in a specific technique, and is a typical Norwegian building method.

Even though Norwegian embankment dams have been built with rip rap the last 30-40 years, there is still little knowledge about the strength of the different rip rap techniques. In 2011, a Energi Norge-financed research program called «Full scale experiments on rip rap of embankment dams» was started at NTNU.

The objective of the master thesis

The main objective of the master thesis figure out how the quality and strength of the rip rap is influenced by placing the stones in an interlocking pattern. It is important for quantifying a possible increase of the factor of safety by placing the stones nicely in a interlocking pattern. Laboratory tests will be carried out to investigate the effect of interlocking pattern on the strength of the rip rap.

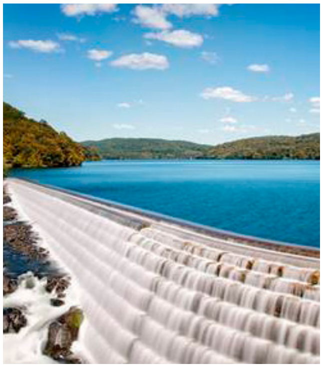
The rip rap at Dam Svartevatn

Background

In Norway regulation stability on isolated grids are not required for small hydropower plant (< 10 MW), compared to what is specified by STATNETT for large hydro. To satisfy this demand, larger hydropower plants often need surge tanks in order to ensure regulation stability. Small hydropower plants are most frequently constructed without such component

The specified limit [MW] for securing of regulation stability is currently under discussion. Due to massive development of wind, small hydro and photovoltaic power projects, the amount of unregulated power in the common grid is increasing, and there is need for more stability in the grid. It is therefor possible that small hydro may have to account for regulation stability in the future.

Small hydro is very sensitive to cost, and the additional cost of a traditional surge system may render many projects unfeasible. It is therefore interesting to investigate alternative solutions which can provide regulation stability for small hydropower projects. This thesis will focus on measures which can be implemented in the waterway design of the hydro power plant.



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Master Thesis

Department of Hydraulic and Environmental Engineering

Innovative Surge Systems for Small Hydro

By Fredrik Staff Edin

Supervisor: Leif Lia
Cosupervisor: Kaspar Vereide

NTNU – Trondheim
Norwegian University of Science and Technology

NVKS
NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Hydraulic and Environmental Engineering

Pumped Storage Hydropower for Delivering Balancing Power and Ancillary Serviced – A Case Study in The Fortun Hydropower System

By Ingunn Norang

Supervisor: Ånund Killingtveit

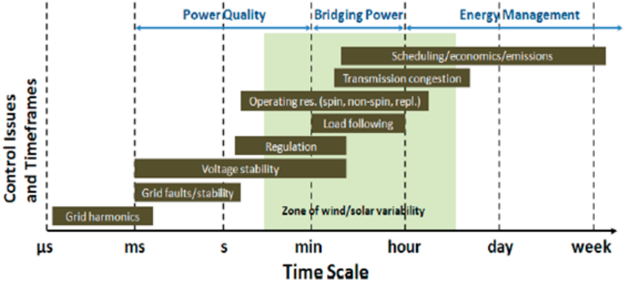
NTNU – Trondheim
Norwegian University of Science and Technology

Background

The power market in Europe is changing rapidly. There is an increased interest for flexible hydropower as the generation capacity of variable renewable energy is increasing. Energy storage, as well as quick response to load change from market participants are crucial for a reliable power system and constant balance between consumption and generation. Pump storage hydropower has the ability to offer regulating power, ancillary services and energy storage possibilities.

The purpose of this study is to investigate existing and future market for ancillary services, and if the added investment and operation costs can be covered by added income from ancillary services.

As a case, we have selected a HPP in the Fortun system, the planned "Fivlemyr-Ilvatn" project. An additional option is to study the existing Herva HPP in the Fortun system. Both these plants are mainly intended for seasonal pumping. The Fortun hydropower system is owned and operated by the company Norsk Hydro. In the case study, the main objective is to compare added income from ancillary services to added cost for construction and operation, analyze optimal capacity and design.



Timeframe for different operating reserves

Illvatn reservoir

Background

Riprap considerably increases the stability of a slope and its resistance against erosion. Therefore, the downstream slopes of rockfill dams built in Norway after 1950 are armed with a riprap by placing oblong stones in an interlocking pattern. Despite that Norwegian dams the last 30-40 years have been built with a riprap design, there is not a lot of knowledge about this building technique. Therefore, in 2011 a research project was initiated by Energy Norway to increase the knowledge about riprap on the downstream slopes of rockfill dams, and in February 2013 a PhD study started about the topic. This Master thesis is a part of a that PhD study.

A smartstone sensor.

The objective of this master thesis is to test «Smartstones», a newly developed sensor which can be placed inside of stones in the riprap. The sensor includes accelerometer, e-compass and gyroscope to register movements. It is a prototype and not yet fully developed.

Example of a rockfill dam with riprap protection.

Laboratory tests will be conducted in a flume, where the downstream side of a scaled rockfill dam will be built. The upper layer will be constructed as riprap and sensors will be placed inside some of the stones. Water will then flow over the riprap and movement in the sensors will be registered. This master thesis will mainly look at displacement and how that can influence the stability of the riprap.

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Master Thesis

Department of Hydraulic and Environmental Engineering

Riprap on Rockfill Dams – Displacement of Riprap and Applications of Smartstone Sensors

By Jens Jakobsen

Supervisor: Priska Helene Hiller and Jochen Aberle

NTNU – Trondheim
Norwegian University of Science and Technology

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Hydraulic and Environmental Engineering

Upgrading and Expansion of Hydropower Plants - Potential

By Mikal Naug Aas

Supervisors: Leif Lia and Ånund Killingtveit

NTNU – Trondheim
Norwegian University of
Science and Technology

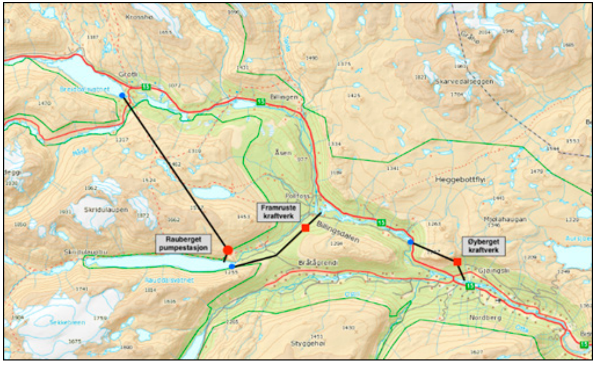
Background

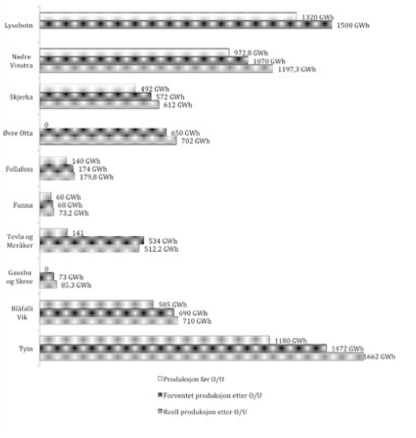
Norwegian hydropower plants have an average age of approximately 45-50 years, and together with future changes in the electricity market it is expected that the Norwegian power system has to be rebuilt.

Upgrading of power plants is often said to have a potential for increased power generation in the range of 2-3 %. However, experience from completed projects shows that upgrading in combination with expansion can release a far higher energy potential than previously estimated.

This thesis will include a thorough review of a sample of projects with the aim to examine how what we define as the energy potential depends on various parameters as electricity pricing, age of the facilities, environmental factors and implementation of reservoirs and pumped-storage facilities etc.

On this basis it will be made an attempt to assess the overall energy potential in upgrading and expansion of hydropower plants in Norway.



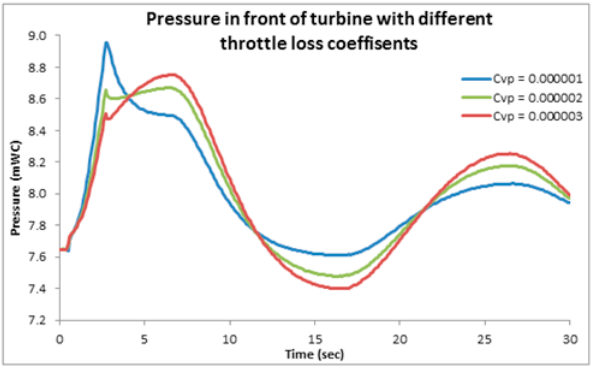


Background

Surge tanks are applied in hydropower plants for dampening of water hammer, and to ensure regulation stability of the power plant. The surge tank may be constructed with a throttle, which introduces a singular loss when water is flowing into or out of the surge tank. Especially for hydropower pumped storage plants the implementation of a throttle is beneficial due to the massive hydraulic transients occurring in such systems.

Design of such throttles is a complex process, and the throttles are designed individually for each power plant. In order to gain further understanding of the throttle effect, and to improve the design of such structures, research is required.

In this master thesis a surge tank throttle will be design and tested in the physical model of Torpa hydropower plant in the laboratory. Then STAR CCM+ will be used to simulate the throttle numerical, and the results will be compared. The 1D simulation software LVTrans will be used to find the best local head loss, which will be used to design the throttle.



Results from LVTrans with different throttle loss coefficients

The air cushion surge chamber in the physical model

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Hydraulic and Environmental Engineering

Physical Modelling of Surge Tank Throttling

By Robert Landskaug

Supervisor:
Professor Leif Lia /
PhD candidate Kaspar Vereide

NTNU – Trondheim
Norwegian University of Science and Technology

NVKS
NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Hydraulic and Environmental Engineering

Pipe Rupture in Small Hydropower Projects

By Tor Oxhovd Svalesen

Supervisor: Leif Lia

NTNU – Trondheim
Norwegian University of
Science and Technology

Pipe rupture

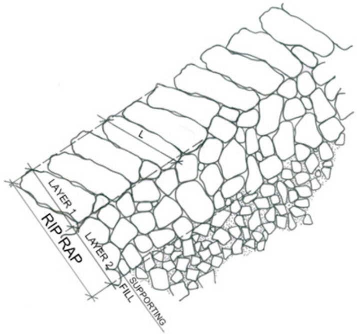
Over the last 10 years Norway have seen a boom in building of small hydropower plants (< 10 MW). Many of these projects use buried pipes to transport the water from inlet to plant. In 2012, around 40 pipe trenches were put into operation. 4 of these (10 %!) experienced several problems with pipe rupture. The safety factor on these pipe trenches is supposed to be 1.5.

The thesis will focus on why these pipes fail, and try to give some recommendations on how installation can be improved to reduce risk of pipe rupture.

Background

Downstream slopes of Norwegian rockfill dams are strengthened with a placed riprap against accidental overtopping or considerable leakage through the dam. Stones are placed in an interlocking pattern with their longest axis inclined towards the dam axis as shown in the figures. The current guidelines are based on the knowledge about dumped riprap despite the stones have to be placed in an interlocking pattern. Hence, there is need for more understanding of the additional strength gained by placed riprap.

Rehabilitation of Svartevatn dam: placement of riprap stones on the downstram slope



Drawing of placed riprap

Objectives of the study

- Literature study of riprap design and practical solutions for steep slopes
- Identification of the hydrodynamic forces due to the flow over steep slopes and flow through the riprap
- Execution and analysis of laboratory tests and large-scale field tests
- Identification of the relevant parameters of the riprap material as well as the effect of placement patterns

This study is financed by Energy Norway and the Research Council of Norway. The support of the collaborating companies in the project “PlaF” is kindly acknowledged.

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NORWEGIAN HYDROPOWER CENTRE

PhD Thesis

Department of Hydraulic and Environmental Engineering

Riprap Design for Rockfill Dams

Priska Helene Hiller

Supervisors: Professor Leif Lia and Professor Jochen Aberle

NTNU – Trondheim
Norwegian University of Science and Technology

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NORWEGIAN HYDROPOWER CENTRE

PhD Thesis

Department of Hydraulic and Environmental Engineering

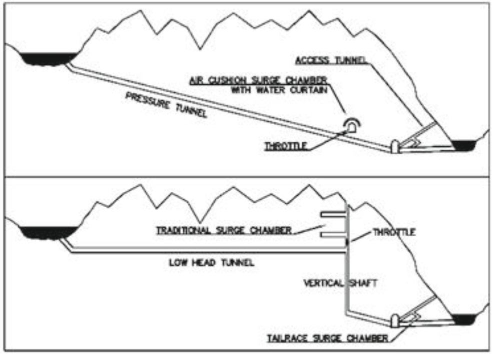
Surge Tank Design for Hydropower Plants

Kaspar Vereide

Supervisors: Leif Lia and Torbjørn Nielsen

NTNU – Trondheim
Norwegian University of
Science and Technology

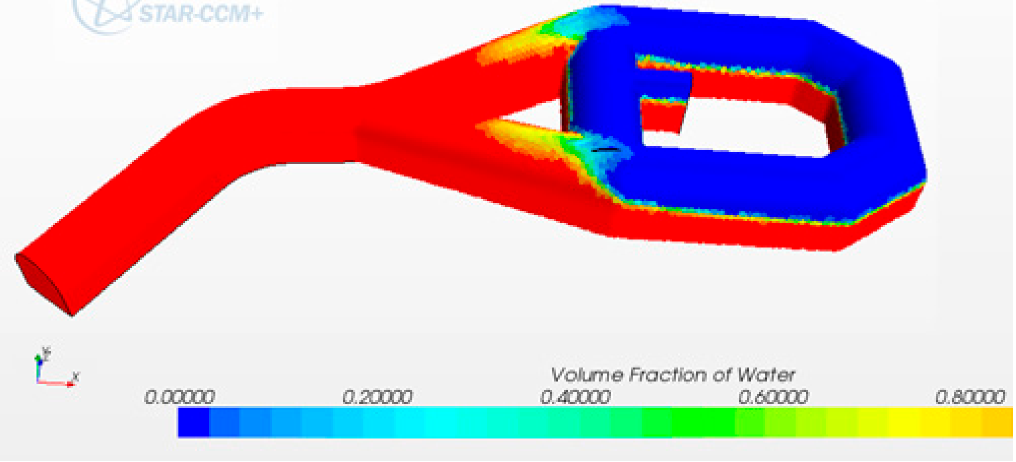
Background



Norwegian hydropower plants are operated with an increasing number of start-stop operations, and variation of produced power. In addition, large hydropower pumped storage projects may be constructed in the near future.

To enable more flexible operation of the power plant, surge tanks may be constructed. The surge tank enables more rapid changes of the produced power, and reduces the pressure forces occuring during such maneuvers. The surge tank is also beneficial for regulation stability in large hydropower plants.

This PhD project seeks to investigate the optimum design of surge tanks, mainly focusing on the air cushion surge tank.



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DEPARTMENT OF GEOLOGY AND MINERAL RESOURCES ENGINEERING – ENGINEERING GEOLOGY

NVKS
NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Geology and Mineral Resources Engineering

Evaluation on potential hydraulic jacking at the high pressure headrace tunnel and stability analysis of underground caverns of Lysebotn II hydropower project

By Lars Emil Eide

Supervisor: Krishna K. Panthi

NTNU – Trondheim
Norwegian University of
Science and Technology

Background

Upgrading of Lysebotn II hydropower plant is underway from an existing installed capacity of 210 MW to 370 MW. This will be achieved by constructing a new underground waterway system including high pressure headrace tunnel, surge chamber, underground powerhouse and transformer cavern, tailrace tunnel and access tunnel.

The MSc thesis consists of:

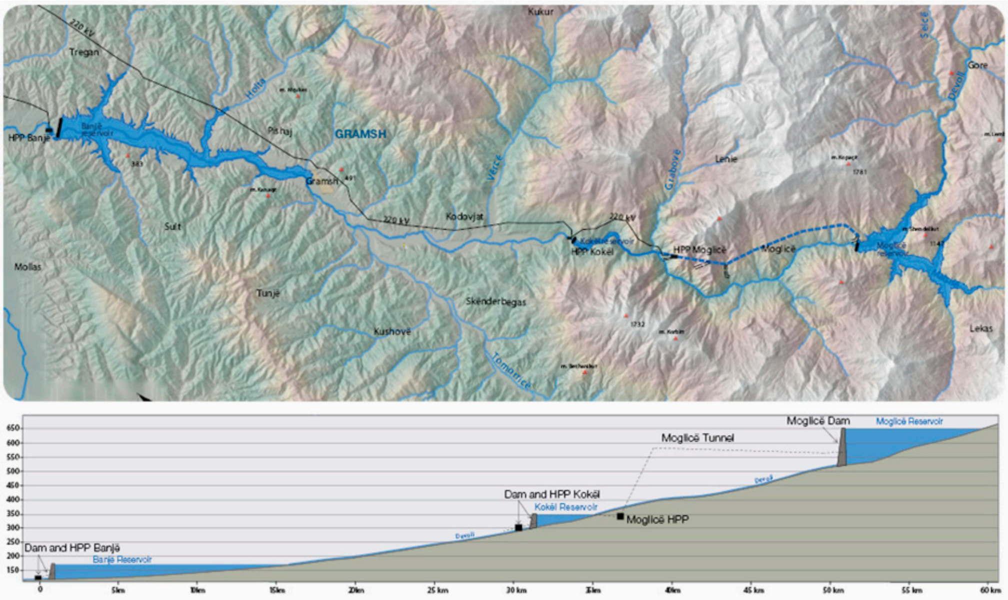
- Analyzing the placement of underground caverns.
- Document mechanical and engineering geological parameters of the rocks and rock masses and estimate in-situ stress conditions at different critical locations.
- Carry out numerical modelling at the selected section to check hydraulic jacking.
- Carry out stability assessment of underground caverns using empirical, analytical and numerical approaches.

The MSc thesis will be carried out inn cooperation with Implenia Norge AS, with Peder Ronny Sødal as co-supervisor.

Background

Mogliĉë HPP is the upper and largest power plant of the Devoll Hydropower Project in Albania. The powerhouse and transformer hall are going to be placed underground. This MSc thesis is to focus on the overall optimization of the orientation and placing of the two caverns and the spacing between them. In addition, detailed stability assessment of the underground powerhouse and transformer caverns will be carried out.

The stability analysis will be assessed through empirical, analytical and numerical approaches. Necessary information about the geology will be collected from existing literature, feasibility reports and previously performed laboratory tests. To perform the numerical stability analysis, the software Phase2 will be used. The MSc thesis will be carried out in cooperation with Sweco Norge AS, with Bent Aagaard as co-supervisor.



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Master Thesis

Department of Geology and Mineral Resources Engineering

Stress induced stability assessment of the underground caverns for Mogliĉë HPP, Albania

By Martin Flåten

Supervisor: Krishna Kanta Panthi

NTNU – Trondheim
Norwegian University of Science and Technology

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NORWEGIAN HYDROPOWER CENTRE

PhD Thesis
Department of Geology and Mineral Resources Engineering

Applicability of Unlined/ Shotcrete Lined High Pressure Tunnels for Hydropower Projects in the Himalaya

By Chhatra Bahadur Basnet

Supervisor
Associate Prof. Krishna K. Panthi

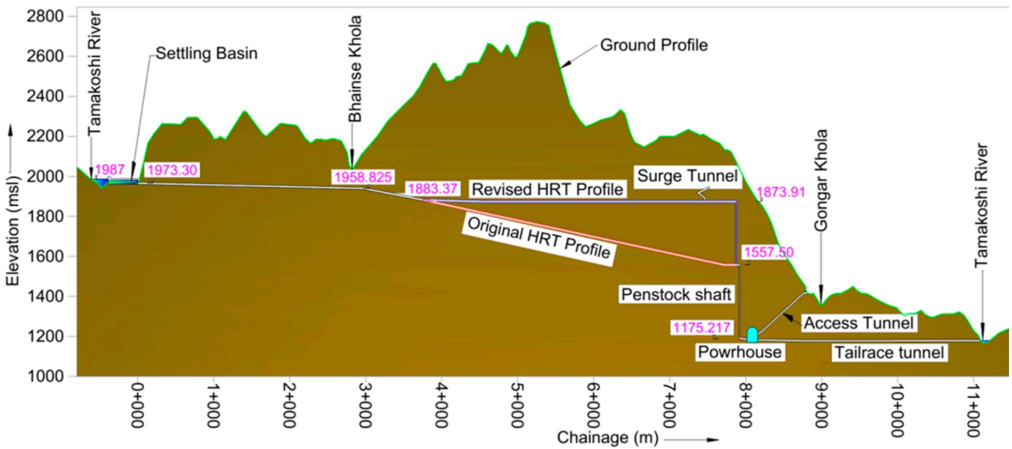
NTNU – Trondheim
Norwegian University of Science and Technology

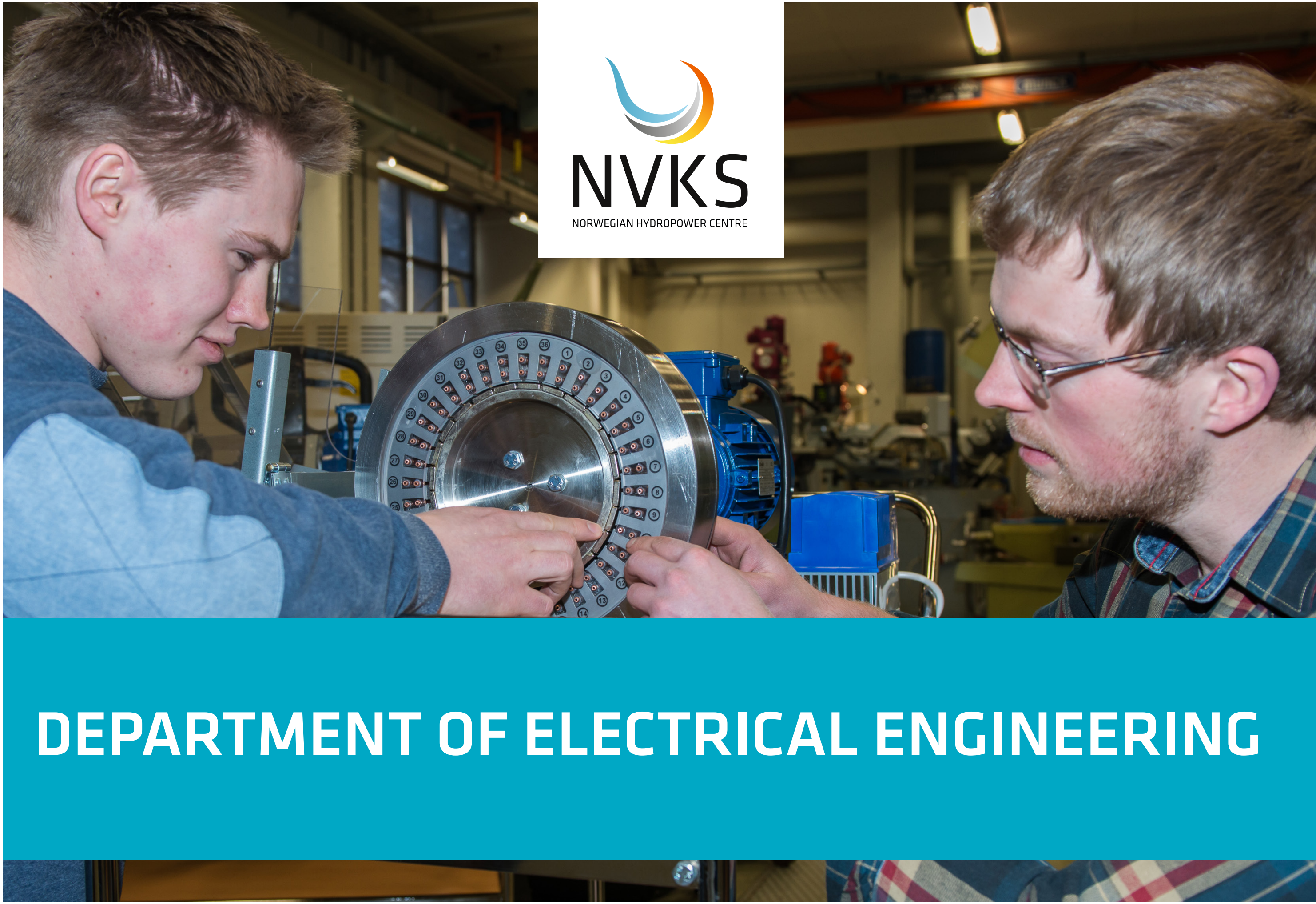
Background
Based on long experience in construction and operation of unlined pressure tunnels and shafts, certain design principles have been developed and practiced in Norway. Now, the research question of this PhD study is;
"Is it possible to adopt Norwegian design principles for unlined pressure tunnels and shafts in the Himalaya? What improvements are needed?"

Objectives

- Review of Norwegian design principles for high pressure unlined tunnels and shafts
- Use of the design principles in project cases from Himalaya and verification using FLAC3D analysis
- Publish the research results in journals and conferences, summarize in a PhD thesis

Cases
Upper Tamakoshi Hydroelectric Project (UTKHP), Khimti 1 Hydropower Project & Khani Khola Hydropower Project, Nepal.





DEPARTMENT OF ELECTRICAL ENGINEERING

Master Thesis

Department of Electrical Engineering

Dynamic Behavior of Synchronous Machines During Open Conductor Fault

By Hans Olav Røste

Supervisor: Trond Toftevåg

NTNU – Trondheim
Norwegian University of
Science and Technology

Background

Open conductor faults occur from time to time in the power system. An open conductor fault in a regional distribution system caused unexpected large poorly damped rotor oscillations in synchronous generators in a power station operated by Nord Trøndelag Elektrisitetsverk.

The main question has been: why did the synchronous generator exhibit this (unusual?) poor damping during this kind of fault?

The dynamic behavior of synchronous machines will be investigated by use of simulation programs, where an equivalent network model is established.

Further work will implement regulators and protection systems in the simulation models, and laboratory experiments

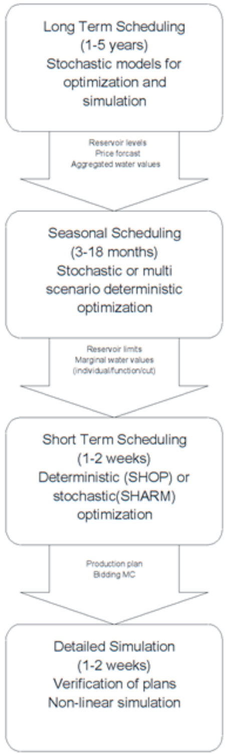
Photograph of conductor fault that caused power oscillations in NTEs network. Taken by technicians in NTE.

Background

A new model for short term planning of hydro power (SHARM-model) has been developed and is being tested in an ongoing research project at SINTEF Energi. SHARM aims at improving the daily production planning when the uncertainty of important parameters increases. The SHARM-model accounts for uncertain market price and inflow to the reservoirs, and will give a better basis for decisions and more robust planning when multiple strategies must be weighed against each other.

The ongoing research project aims at finding out if a stochastic formulation gives a possibility of increased economic earnings or other operational improvements, as well as how such a model can be operationalized at the producers.

The short term model is coupled to the seasonal model through water values that are used to assess the water in the timeframe of the short term model. The water value represents the resource cost of the water and it is important that the coupling between the models is consistent. In SHARM the water value may be descirved as either a constant end value per Mm3 or by use of cuts from the seasonal model. The use of cuts is especially suited in a stochastic model because the uncertainty makes multiple end states possible. In a deterministic model where only one course is given, there is a rather narrow band of possible end states given by things like maximum and minimum production. Because of this it is interesting to look at the use of cuts in a deterministic versus a stochastic model. What cuts are chosen by the deterministic model? What cuts are chosen by the stochastic? Does the stochastic model need more cuts as input? In that case, what does it depend on? Does more extreme variations in price and inflow require more extreme cuts?



Hydro scheduling hierarchy

NVKS
NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Electrical Engineering

Analysis of End Conditions for a Stochastic Short Term Model

By Håvard Hansen

Supervisor: Magnus Korpås

NTNU – Trondheim
Norwegian University of Science and Technology

Master Thesis

Department of Electrical Engineering

Optimal Hydro Power Scheduling in Multiple Power Markets

By Caroline Rasmussen og Jakob Boye Hansen

Supervisor: Magnus Korpås
Co-supervisor: Marte Fodstad

NTNU – Trondheim
Norwegian University of Science and Technology

Background

The main topic of this project has been to study the production scheduling of a hydro power producer exposed to the day-ahead and balancing market. The objective was to find what profit the producer may achieve by strategically bidding in the above mentioned markets.

The background for the thesis is the increasing penetration of renewable energy in the energy sector. Hydro power flexibility can support a stable power balance, thus mitigating the effect of intermittent energy.

A prototype model that undertakes this task has been developed by SINTEF Energy Research as a part of their project 'Integrating Balancing Markets in Hydro Power Scheduling Methods'.

To examine the potential profit a producer may gain by participating in the balancing market, the model has been run with and without the balancing market included in the simulation. The Tokke-Vinje hydro power system has been selected as a case study.

Våmartveit dam

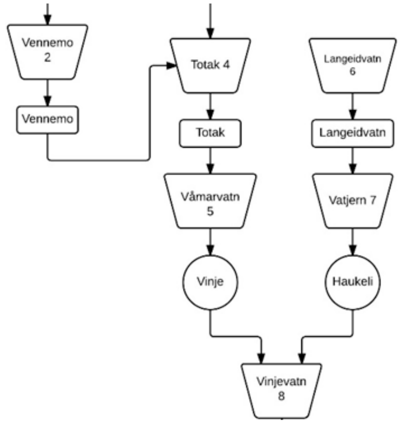


Illustration of the Tokke-Vinje Hydro power system

Background

The background of this master thesis is to investigate the possibilities to use a permanent magnet (Fig1) generator in a small scale pumped storage power plant, as a cost effective alternative in providing a stable system support in the Norwegian grid. The main benefits by using a PM is mainly a less complicated design of the machinery and plant installation, at a lower cost than the traditional synchronous machine with a electromagnet in the rotor.

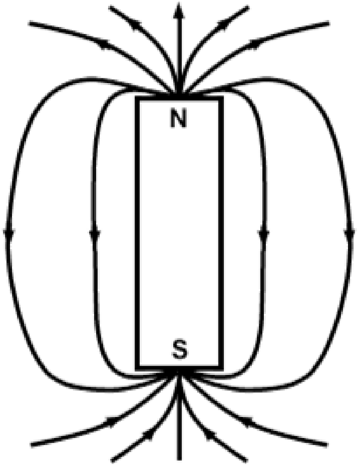


Fig1:
Permanent magnet, with magnetic field lines

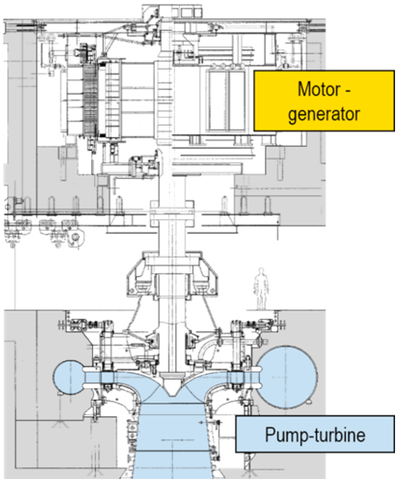


Fig2:
Reversible pump turbine

The project is built up around a fictitious hydro power location, with a given grid connection. The generator is chosen to 15 MW, as a reversible pump turbine configuration (Fig2). The considerations around starting up a permanent magnet machine in pump operation is to be explored, together with the effects of grid connection requirements such a generating unit is met with. Simulations of the pumped hydro power plant are executed in the simulation program Matlab Simulink SimPowerSystems.

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Master Thesis

Department of Electrical Engineering

Simulation and Evaluation of a Small Scale Pump Storage Plant With PM Generator

By Lornts Mikal Sklett

Supervisor: Arne Nysveen

NTNU – Trondheim
Norwegian University of Science and Technology

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NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Electrical Engineering

PM Synchronous Machine for Pumped Storage Plant

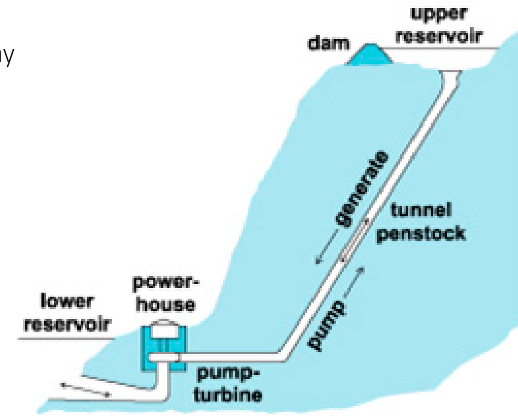
By Svein Kristian Wedum

Supervisor: Arne Nysveen

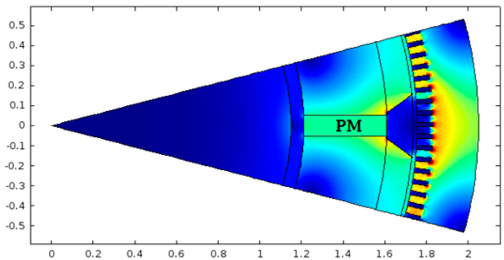
NTNU – Trondheim
Norwegian University of Science and Technology

Background

A reservoir of water with potential energy may be the most efficient way of energy storage in large quantities with today's technology. Pumped storage hydropower plants can be used when integrating large volumes of renewable energy as solar- and wind power in the power system. The amount of power delivered from these plants is strongly dependent of the season as well as the weather of the day. Pumped storage plants can provide assistance to obtain a balanced and stable power system. This can also be combined with small-scale hydropower, and the scope of this thesis is 15 – 20 MW in range of power. Traditionally ordinary synchronous machines are used in hydropower plants, with its field windings for exciting the rotor.



Principle of pumped storage hydro power plant



Simulation in COMSOL: Machine segment including one PM covering two half poles.

In this thesis the idea is to use a permanent magnet synchronous machine instead. This may be a suitable solution for a machine in this power range, and can give advantages considering simplicity of the machine in addition to utilization of space.

A simplified design is proposed and analysed using COMSOL. The air gap flux obtained is in the range of what required, but analysis using a more complex model is needed. The use and modification of a Matlab-tool may be necessary to easier find solutions for different designs.

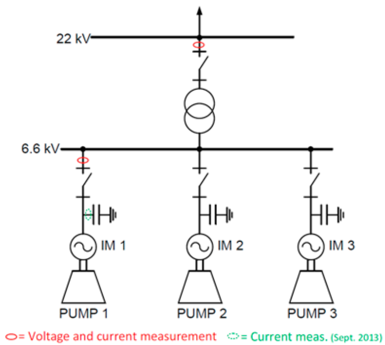
Background

A few years back, some low voltage end consumers in Trøndelag complained about very poor lighting quality. The problem was described as slow, but distinct flicker, easily noticeable by the human eye. Extensive measurements revealed that the problem was caused by asynchronous machines operating in parallel with capacitor banks at a hydro pump station nearby.

Fifth and seventh harmonics that resonate with the capacitor banks is assumed to cause the flicker. However, exactly what cause the harmonics and how they interact with the asynchronous machines in the hydro pump station to create this specific distortion, is still not clarified. The objective of the thesis is to process data from the measurements, to extract more information from them. Also, experiments in the laboratory will be performed and the results will be used to evaluate the latest theory for the cause of the flicker.

For the laboratory exercise, one of NTNU's asynchronous machines with wound rotor will be used. To control the input signal and create similar conditions to those at the pump station, a frequency converter will be used. Also, FEM simulation using COMSOL software is planned.

The wound rotors used in the motors at the pump station are likely to play a part in creating the disturbance.



Line diagram of hydro pump station with three asynchronous motors and accompanying capacitor banks.

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Master Thesis

Department of Electrical Engineering

HV Wound-Rotor Induction Machines – Harmonic Field Effects and Power Quality Issues

By Torstein Kastet

Supervisor: Trond Toftevaag

NTNU – Trondheim
Norwegian University of Science and Technology

NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Electrical Engineering

A Technical-Economic Analysis of Reinvestment Requirements in Hydropower Plants

By: Lasse Brekke

Supervisor: Eivind Solvang

NTNU – Trondheim
Norwegian University of Science and Technology

Background

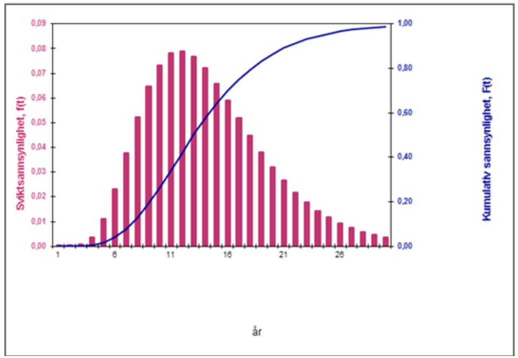
Ca. 99% of Norway's energy is produced by hydropower distributed on 1476 hydroelectric power plants pr. 01.01.2014. In order to maintain the operation of the hydropower plants, maintenance and reinvestments is necessary.

A technical-economic analysis of reinvestment requirements is implemented for a better basis for the assessments and decisions to be adopted by maintenance and reinvestments in the power industry.

The plant, which is analyzed in this project is Litjfossen power plant. Litjfossen power plant was put into operation in 1982 and operated by TrønderEnergi. The plant has been in operation for over 30 years without major reinvestments and the risk of failure is increasing. The main objective of the task is to perform a technical-economic analysis on Litjfossen power plant to better the decision-making basis for the relevant maintenance and reinvestment options available.

The task will include an overarching picture of the whole station with a main focus on assessing the components with the highest risk of failure.

Runner Litjfossen power plant



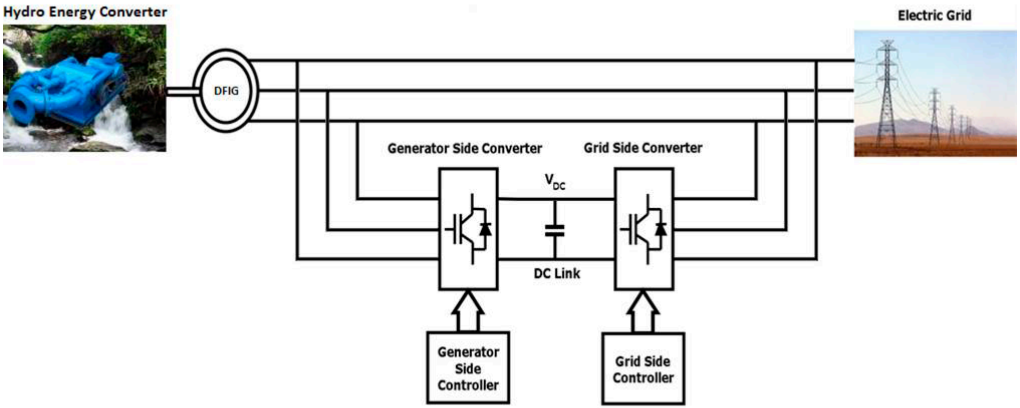
Residual lifetime calculations on type of damage S2
– Cavitation Runner Litjfossen power plant

Background

Doubly Fed Induction Generators (DFIG) has been very popular and widely used in conjunction with wind power conversion systems due to their good range of speed control with reduced converter size as Norway produces almost all its power from hydro source which includes from large to medium and small generation systems and usually employs synchronous generators to convert mechanical energy into electrical.

The objective of this thesis is to perform a study whether application of a doubly-fed induction generator in Mini-hydro power plants can be a feasible technical and economical solution or not.

This task will be carried out by first performing the theoretical studies and simulation in Matlab/Simulink by developing DFIG control with mini-hydro turbine and subsequently implementing that control by establishing a laboratory setup to verify/validate the simulation results/model while economic assessment is an optional task.



DFIG control in mini-hydro power generation system

NVKS
NORWEGIAN HYDROPOWER CENTRE

Master Thesis

Department of Electrical Engineering

Doubly Fed Induction Generator for use in Mini-hydro power plants

By Rizwan Rafique

Supervisor: Trond Toftevaag

NTNU – Trondheim
Norwegian University of Science and Technology

NVKS
NORWEGIAN HYDROPOWER CENTRE

PhD Thesis
Department of Electrical Engineering

Design of Variable Speed Generators for Hydropower Applications

By Erlend L. Engevik

Supervisor: Arne Nysveen

NTNU – Trondheim
Norwegian University of Science and Technology

Background

The power system is experiencing an increasing share of electric power production that comes from intermittent power sources like wind and solar energy. Increased pressure is put on controllable power sources like hydropower to deal with fluctuations in the output of electric power.

Generators used in hydropower plants today are not designed and optimized for frequent changes in active power production. When traditional hydropower generators are used, the nominal rotational speed is set by the grid frequency and the number of poles in the machine.

The main purpose of this work is to develop synchronous generator designs where the speed of rotation and electrical frequency is allowed to vary within given intervals. The work will also look at possibilities for reducing the moment of inertia in the machine.

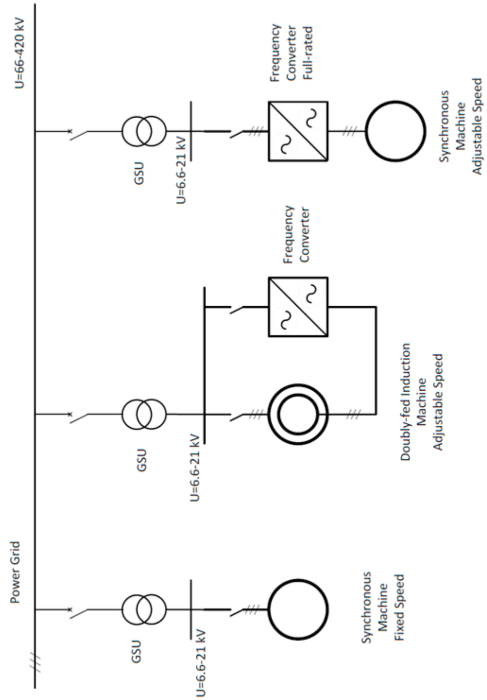
This work will be a theoretical study. Focus will be on using modern numerical software for design and optimization of synchronous machines.

Background

- Synchronous generators in hydro power plants normally operate at a constant speed and are directly connected to the grid.
- Variable-speed operation of the hydro generators could increase the flexibility of hydro generation and enable the optimal operation of the turbine.
- In this system, rotational speed does not need to be constant.
- Two alternatives: (1) Synchronous generator connected to a full-rated converter. (2) oubly-fed induction generator.

Objectives

- Primary objective: design and analysis of a variable-speed energy conversation system for hydro power plants and investigation of the alternatives mentioned before.
- New design considerations for the generator will be studied. (rotational speed and frequency can be chosen more freely). This includes both electrical and mechanical parameters.
- Associated power electronic systems will be investigated.
- Operation in pumping mode will be analyzed.



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Post Doc. Project

Department of Electrical Engineering

Variable Speed Energy Conversion Systems for Hydro Power Plants

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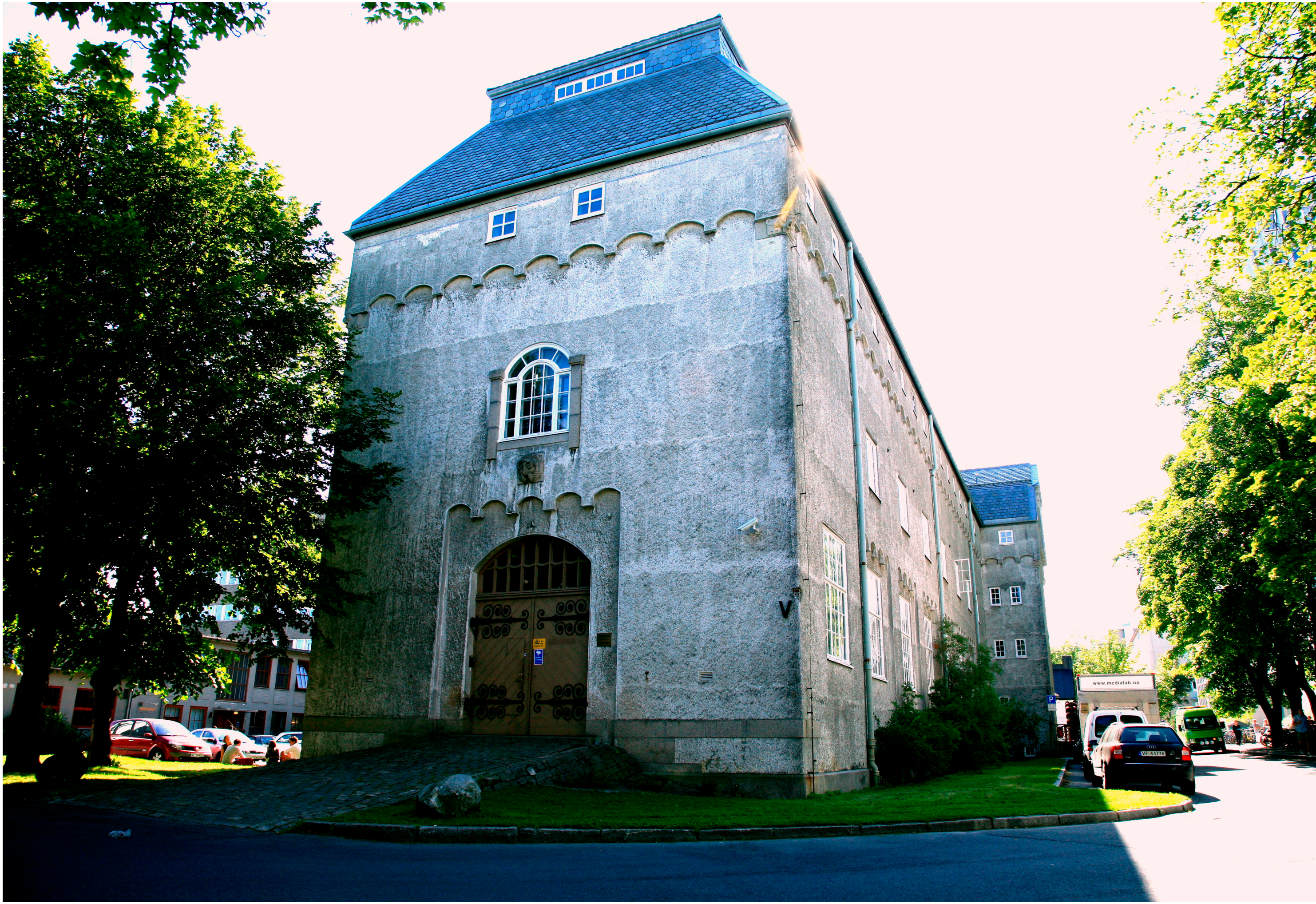
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